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LITTER AND NUTRIENTS (N, P, K, Ca) IN FOREST FLOOR HORIZONS OF LODGEPOLE PINE STANDS IN COLORADO

Report to the U.S. Forest Service on Line Project No. FS-RM-1201 (Contract No. 16-127)

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ABSTRACT

Material from forest floor horizons (L, F1, F2, A&D) was collected from eight lodgepole pine stands of contrasting densities, site indices, average Dbh, and stand height. Tabular data are given for loss-on-ignition, mineral and ash content, and total N, P, K, and Ca in these horizons. Total litter ranged from 23,000 to 37,000 pounds per acre, but was not related to stand density. Total N on the forest floor ranged from 290-480 pounds per acre, total Ca from 230-560 ppa, total K from 110-270 ppa, and total P from 20-44 ppa in the pine stands. The most mobile nutrients were K and P. These were generally most concentrated in the A&D horizon whereas Ca was about equally distributed in each of the four horizons. The proportion of N increased with progressive decomposition of the pine litter. Simple correlations between stem volume and both P and K and between the height of dominant trees and both N and P were significant. It is suggested that the response of lodgepole pine to fertilizers, with particular emphasis on P and K, should be tested in field trials.

INTRODUCTION

The organic material of the forest floor is an important part of the total forest ecosystem. As a major pathway of the nutrient cycle, litter layers may affect forest productivity by locking up major nutrients and releasing them at slow rates. The amount of nutrients contained in the litter has been measured in a variety of pine forests (e.g. Tamm 1959, Ovington 1959, Will 1959, Kaesalu 1965, Wells and Davies 1966), but nutrient quantities in lodgepole pine (Pinus contorta) forests have not been studied. However, individual trees in these forests may show very slow growth, especially in highly stocked stands. In the Front Range of Colorado occur many stands of lodgepole pine showing low productivity. This study was made to determine if low productivity could be, in part, the consequence of poor soil nutrition. Total levels of N, P, K, and Ca were measured in forest floor horizons in eight lodgepole pine stands ranging from very dense and poor growth to stands of low density and more rapid growth. This paper reports litter and nutrient quantities in the L, F1, F2, and A&D horizons of these stands.

THE STUDY AREA

The lodgepole pine stands occur on the Rocky Mountain sub-summit peneplain of the east slope of the Front Range in Colorado. Seven stands are between 8200-8450 feet elevation on gentle (1-24% slope) upland topography. These stands

are in the *Pseudotsuga manziesii* zone of forest classification (Daubenmire 1943). The mean annual precipitation is about 20 inches, occurring as summer orographic and convectional showers and as winter snowfall. There is often a long, dry period in fall. An eighth stand (LHLP2) is at 9100 feet elevation on a moderate (27%) slope in the *Picea engelmanni-Abies lasiocarpa* zone (Daubenmire 1943). Precipitation is probably somewhat higher and mean monthly temperatures somewhat lower in this stand. Climatic data in this region have been described by Marr (1961).

The soils are well drained, gravelly sandy loams and gravelly loamy sands derived from granitic parent materials. They are moderately acid Gray Wooded and thick Gray Wooded soils (Johnson and Cline 1965) related to the Edloe Series. Detailed profiles are given in the Appendix. Surface litter horizons (L, F1, F2) form a continuous mat about 1 inch thick. There is little duff; instead highly decomposed, fine litter fragments are incorporated into the uppermost mineral horizon (A&D) to form a wavy layer usually less than ½ inch thick. This horizon may be blackened with charcoal, and it may also be irregular or broken by the presence of old, decayed wood (McFee and Stone 1966). The Gray Wooded A2 may be up to 14 inches thick. The uppermost part of this horizon is often modified by slight iron translocation to form a weak Brown Podsolic (Johnson and Cline 1965) profile. Pine roots are most numerous in the upper foot of mineral soil.

Lodgepole pine is the major forest cover in the study area. The stands are purely of lodgepole pine, for succession by *Pseudotsuga mensiesii*, *Abies lasiocarpa*, and *Picea engelmanni* is not evident. All of the stands except

1-3 appear to have originated through fire and/or logging in the early 1900s, and most of the trees seem to have become established in the first decade after fire (Mason 1915). Stand 1-3 is older, although it, too, was thinned by a fire in the early 1900s and by subsequent logging. Stand 4-3 was uniform thinned to about 8 x 8 foot stem spacing. The ground flora is generally sparse under closed-canopy lodgepole pine stands. Shrubs include Shepherdia canadensis, Juniperus communis, Rosa sp., and Arctostaphylos uva-ursi, and the most frequent herbs are Pyrola virens, Geranium fremontii and Potentilla fissa.

METHODS

Each pine stand was delineated in an area of population homogeneity as judged visually. The sample area was placed near the center of the population and was sufficiently distant from other pine populations that litterfall was presumed to be entirely from the population being sampled. Rectangular macroplots were marked out--10 x 5 m in high density forests and 15 x 10 m or larger in forests with 1,600 stems per acre or less. A 1 or 2 meter buffer strip was included with the smaller macroplots for measurements of Dbh and stand density. Within the macroplots at least seven 0.25 m^2 microplots were located by randomization. Litter was collected after separation of L, F1, and F2 horizons in the field. The uppermost mineral horizon (A&D) was collected to the depth of the underlying A1, A2, or B2ir horizon. The collections from each microplot were air-dried, weighed, homogenized, and subsampled prior to laboratory determinations. Homogenization

of L, F1, and F2 horizons was performed by grinding all material first through a meat grinder and then, after quartering, through a coffee mill. The grinders were cleaned after each operation to avoid contamination. The A&D material was screened in a 2mm sieve, and the fraction passing the sieve was weighed and mixed. About 30g of the less than 2mm material was ground to pass a 0.5 mm sieve and used for laboratory analyses. To facilitate nutrient determinations homogenized material from like horizons of the microplots of each stand was pooled by taking nearly equal volumes and mixing.

Laboratory determinations were made on air-dry material, but quantities are reported on an oven-dry basis. Oven drying was done at 60-70°C for a minimum of 10 hours on litter and overnight at 105°C for A&D material. Loss-on-ignition was found by heating samples at 500°C for one hour in a muffle furnace. Tissue for chemical analyses was dry ashed at 450°C for one hour. Loss by puffing was minimized by placing samples in a cold furnace and covering the crucibles with a perforated disc. After dissolving the ash in concentrated HCl the excess acid was evaporated nearly to dryness, and the residue was redissolved in 0.1N HCl and filtered into 100 ml volumetric flasks. Potassium and calcium were measured by flame photometry; phosphorus by the colorimetric determination of molybdenum blue. Material for nitrogen analysis was digested and analysed by semi-micro Kjeldahl procedures. All determinations were duplicated and the mean values reported.

RESULTS AND DISCUSSION

Litter and Pine Stand Parameters

Tables 1-3 give lodgepole pine stand parameters and characteristics of the litter accumulated in the stands.

Table 1. Pinus contorta stands at 8200-9100 feet elevation on the east slopes of the Colorado Front Range.

STAND	DENSITY[a] Stems/acre	DBH in. Ave	DBH in. Range	BASAL AREA Ft^2/acre	HEIGHT[c] feet	AGE years[d] Ave	AGE years[d] Range	SITE INDEX[e]	GROUND FLORA Cover %	GROUND FLORA Shoot Biomass lb/acre
MLP2-2	14,200	1.2	0-3	138	15	60	53-67	59	2.6	
2-1	7,300	1.8	0-3	161	27	60	53-67	67	4.8	
4-1	4,500	2.6	1-4	181	28	64	49-68	62	2.8	
4-2	3,600	2.6	1-5	157	26	63	51-67	55	0.2	
1-1	3,600	2.8	1-5	164	30	65	58-68	59	0.2	
1-3	1,200	5.2	3-8	194	41	98[b]	96-99	50	1.5	
4-3[f]	700	4.8	3-7[g]	61	26	61	34-67[g]	40	23.6	10.3
LHLP2	1,600	5.2	2-8	252	51	67	49-73	90	14.1	4.8

Notes a- not adjusted for slope, b- trees are survivors of a fire in 1900-1905, c- mean height of at least 5 dominant trees, d- reference year 1966, e- after Alexander 1966, f- uniform thinned stand, g- does not include pine regeneration subsequent to thinning.

Table 2. Litter as loss-on-ignition (Kg/m^2) in forest floor horizons in Colorado *Pinus contorta* stands. Coefficient of variation (percent) in parentheses.

STAND	DENSITY (stems per m^2)	SAMPLE AREA (m^2)	HORIZON L	F1	F2	A&D	Total
MLP2-2	3.5	1.75	1.04 (18)	0.96 (44)	0.35 (106)	0.60 (23)	2.95 (30)
2-1	1.8	1.60	1.05 (29)	0.77 (21)	0.37 (53)	0.35 (110)	2.54 (23)
4-1	1.1	1.75	1.21 (15)	1.32 (30)	0.62 (32)	0.46 (34)	3.62 (17)
4-2	0.9	1.75	1.09 (15)	1.33 (105)	0.77 (33)	0.44 (31)	3.62 (43)
1-1	0.9	1.75	0.99 (14)	1.04 (21)	0.74 (48)	0.38 (89)	3.16 (15)
1-3	0.3	2.00	1.42 (15)	1.48 (118)	0.60 (62)	0.70 (31)	4.21 (53)
4-3	0.2	4.00	1.10 (29)	0.90 (108)	0.51 (107)	0.33 (76)	2.85 (51)
LHLP2	0.4	2.00	0.98 (17)	1.32 (58)	0.88 (29)	0.68 (56)	3.86 (33)
Mean			1.11 (13)	1.14 (22)	0.60 (34)	0.49 (32)	3.35 (17)

Conversion 1 Kg/m^2 = 8,900 pounds per acre.

Table 3. Mineral and ash in forest floor horizons of *Pinus contorta* stands in Colorado. Numbers in percent oven-dry material.

STAND	HORIZON			
	L	F1	F2	A&D
MLP2-2	7.4	25.7	43.7	78.4
2-1	9.3	38.6	63.8	82.0
4-1	9.2	30.1	51.2	87.2
4-2	9.1	24.4	43.8	87.2
1-1	6.9	29.5	62.5	92.1
1-3	8.1	23.1	44.9	77.3
4-3	16.4	32.1	51.5	81.1
LHLP2	11.8	44.6	56.3	73.1
Mean	9.8	31.0	52.2	82.3

The litter is almost entirely derived from the pine, since ground flora is very sparse (Table 1). A small contribution to the litter comes from droppings of deer and rabbits, but this is also of minor importance, chemically, in comparison to the volume of pine debris. Total litter weights range from 2.54-4.21 Kg/m^2 (23,000-37,000 pounds per acre) and show little relationship to stand density. Studies from other closed-canopy pine forests also showed little affect upon litter production resulting from differences in tree density (Bray and Gorham 1964). About 60-72% of total litter was found in the L and F1 horizons. The average littercast during the 12-month period starting in August, 1966 was 0.49 ± 0.08 Kg/m^2 (90% confidence interval) on a loss-on-ignition basis. Thus Table 2 suggests that the L layer could represent about 2 years of nearly undecomposed accumulation in each stand.

The distribution of litter within the stands is highly variable (Table 2). The L layer is usually least variable, perhaps because of the uniformity of needlecast in the closed-canopy stands. The 29% variation in the L layer of stand 4-3 is partly due to the openings between tree canopies through uniform thinning. Generally the variations above 50% arise from the high proportion of charcoal or old wood in the F1, F2, and A&D horizons. The reddish, partly decayed old wood produced large increases in litter weight in about 6% of the sample areas and contributed at least 14% of the total litter weight of the forest floor (these figures were computed from the strongly bimodal distribution of total litter weights). Since old wood decays very slowly (McFee and Stone 1966), this variation could reflect forest floor conditions before establishment of the present trees. A source of variation not shown in Table 2 are the squirrel middens with accumulated

cone material at the base of occasional trees throughout the lodgepole pine forest area.

Table 3 gives the percent mineral and ash residue upon ignition of materials from each forest floor horizon. The increase of ignition residues with forest floor depth is apparent in each stand. Soil minerals appear to contribute to the oven-dry material in increasing proportion with depth. Soil arthropods are abundant in litter layers, especially when the litter is moist, and are probably important agents in soil-litter mixing. Grunert (1964) has suggested that dust is an important factor in nutrient cycling.

Nutrients

Tables 4-11 give data on N, K, Ca, and P in forest floor horizons of the eight lodgepole pine stands. Total N ranged from 33-54 g/m^2 (290-480 pounds per acre) in seven pine stands. About 60% of these amounts was found in the L and F1 horizons where greatest organic accumulation also occurred. Total N values in Table 4 are similar to reports of N accumulation in litter of pine stands in northern Europe (Ovington 1959, Tamm 1959). The percentages in Table 5 are similar to data reported by Wells and Davies (1966) in a variety of pine forests in southeastern United States. Nitrogen percentages generally increased with progressive stages of litter decomposition in forest floor horizons. In the Colorado lodgepole pine stands the most pronounced increase in N percentages occurred in the F1 horizon. Further increases in the F2 and A&D horizons were not as strong, possibly because of the presence of charcoal, old wood, or other low-N materials in these layers. Wells and Davies (1966) found the trend of increasing N percentage with

Table 4. Total nitrogen (grams/meter^2) in forest floor horizons of Colorado *Pinus contorta* stands

STAND	HORIZON L	F1	F2	A&D	Total
MLP2-2	7.5	11.7	4.7	9.2	33
2-1	8.8	12.0	5.1	6.0	31
4-1	10.6	17.4	9.0	7.5	45
4-2	9.6	14.9	10.9	6.1	42
1-1	7.4	13.3	8.4	5.1	34
1-3	10.9	19.7	8.6	9.9	49
4-3					
LHLP2	8.8	18.5	14.4	12.2	54
Mean	9.1	15.4	8.7	8.0	41

Table 5. Total nitrogen in relation to loss-on-ignition weight of forest floor horizons in Colorado *Pinus contorta* stands. Numbers in percent.

STAND	HORIZON L	F1	F2	A&D	Total
MLP2-2	0.72	1.22	1.34	1.53	1.12
2-1	0.84	1.56	1.37	1.70	1.22
4-1	0.88	1.32	1.46	1.64	1.24
4-2	0.88	1.12	1.41	1.38	1.16
1-1	0.75	1.28	1.14	1.34	1.08
1-3	0.77	1.33	1.44	1.42	1.16
4-3					
LHLP2	0.90	1.40	1.64	1.79	1.40
Mean	0.82	1.32	1.40	1.54	1.22

Table 6. Total potassium in forest floor horizons in Colorado *Pinus contorta* stands. Numbers in grams/meter^2.

STAND	HORIZON				
	L	F1	F2	A&D	Total
MLP2-2	2.08	3.84	1.75	9.00	16.7
2-1	2.10	3.85	2.59	3.50	12.0
4-1	3.39	5.28	4.15	8.56	21.4
4-2	2.83	4.26	4.47	5.94	17.5
1-1	1.98	4.16	5.92	17.47	30.0
1-3	2.84	5.92	3.00	8.40	20.2
4-3	2.75	4.05	3.01	5.94	15.8
LHLP2	2.35	6.60	6.86	10.54	26.4
Mean	2.54	4.74	3.97	8.67	20.0

Table 7. Total potassium in relation to loss-om-ignition weight of forest floor horizons in Colorado *Pinus contorta* stands. Numbers in percent.

STAND	HORIZON				
	L	F1	F2	A&D	Total
MLP2-2	0.2	0.4	0.5	1.5	0.6
2-1	0.2	0.5	0.7	1.0	0.5
4-1	0.3	0.4	0.7	1.9	0.6
4-2	0.3	0.3	0.6	1.3	0.5
1-1	0.2	0.4	0.8	4.6	1.0
1-3	0.2	0.4	0.5	1.2	0.5
4-3	0.3	0.4	0.6	1.8	0.6
LHLP2	0.2	0.5	0.8	1.6	0.7
Mean	0.2	0.4	0.6	1.9	0.6

Table 8. Total calcium in forest floor horizons of Colorado *Pinus contorta* stands. Numbers in grams/meter^2.

STAND	HORIZON				
	L	F1	F2	A&D	Total
MLP2-2	12.5	9.6	4.6	10.2	37
2-1	15.8	10.8	5.2	6.3	37
4-1	9.7	9.2	4.3	3.2	26
4-2	10.9	12.0	7.7	3.5	34
1-1	12.0	10.4	8.2	8.0	39
1-3	21.3	19.2	10.2	12.6	63
4-3	11.0	8.0	3.4	7.3	30
LHLP2	9.8	7.9	5.3	8.2	31
Mean	12.9	10.9	6.1	7.4	37

Table 9. Total calcium in relation to loss-on-ignition weight of forest floor horizons in Colorado *Pinus contorta* stands. Numbers in percent.

STAND	HORIZON				
	L	F1	F2	A&D	Total
MLP2-2	1.2	1.0	1.3	1.7	1.3
2-1	1.5	1.4	1.4	1.8	1.5
4-1	0.8	0.7	0.7	0.7	0.7
4-2	1.0	0.9	1.0	0.8	0.9
1-1	1.2	1.0	1.1	2.1	1.2
1-3	1.5	1.3	1.7	1.8	1.5
4-3	1.0	0.9	0.7	2.2	1.1
LHLP2	1.0	0.6	0.6	1.2	0.8
Mean	1.2	1.0	1.1	1.5	1.1

Table 10. Total phosphorus in forest floor horizons in Colorado *Pinus contorta* stands. Numbers in g/m^2.

STAND	HORIZON				
	L	F1	F2	A&D	Total
MLP2-2	0.42	0.77	0.28	0.72	2.2
2-1	0.94	1.16	0.59	1.02	3.7
4-1	0.97	1.58	0.87	1.52	4.9
4-2	0.87	1.20	0.69	1.06	3.8
1-1	0.59	0.62	0.74	1.48	3.4
1-3	0.57	1.63	0.90	1.68	4.8
4-3	0.66	0.72	0.51	1.12	3.0
LHLP2	0.78	1.58	1.23	1.36	5.0
Mean	0.72	1.16	0.73	1.24	3.8

Table 11. Total phosphorus in relation to loss-on-ignition weight of forest floor horizons in Colorado *Pinus contorta* stands. Numbers in percent.

STAND	HORIZON				
	L	F1	F2	A&D	Total
MLP2-2	0.04	0.08	0.08	0.12	0.07
2-1	0.09	0.15	0.16	0.29	0.14
4-1	0.08	0.12	0.14	0.33	0.14
4-2	0.08	0.09	0.09	0.24	0.10
1-1	0.06	0.06	0.10	0.39	0.11
1-3	0.04	0.11	0.15	0.24	0.11
4-3	0.06	0.08	0.10	0.34	0.10
LHLP2	0.08	0.12	0.14	0.20	0.13
Mean	0.06	0.10	0.12	0.27	0.11

litter decomposition to be highly correlated to the cation-exchange capacity of forest floor materials.

Total potassium on the forest floor was from 12 to 30 g/m^2 (110-270 pounds per acre) with greatest amounts in the A&D horizon and lowest amounts in the L horizon (Table 6). In every stand the proportion of K with respect to loss-on-ignition material increased in successive forest floor horizons (Table 7). Many workers (e.g. Manakov 1962, Livens and Vanstallen 1957, Kartashov 1961) have shown that K is readily leached from forest litter. Its accumulation and retention in the A&D horizon may be caused primarily by the high cation exchange capacity of this horizon. Since it is likely that this horizon has a considerably higher CEC than at least several inches of underlying coarse-textured mineral soil (Wells and Davies 1966), the A&D may be the most effective trap against removal of K cations from the forest ecosystem.

Total calcium was 26-63 g/m^2 (230-560 pounds per acre) in the combined forest floor horizons of the lodgepole pine stands. Highest levels were found in the L and F1 horizons (Table 8), but the ratio of Ca to loss-on-ignition weights were nearly the same in each horizon (Table 9). These data suggest that Ca, although leached to some degree from litter horizons, is much less mobile than K on the forest floor.

Total phosphorus was at low levels, ranging from 20-44 pounds per acre in the eight stands. These levels are slightly higher than P in the litter of 35 and 55-year _Pinus sylvestris_ plantations in England (Ovington 1959). The ratio of P to loss-on-ignition increases in successive forest floor horizons, and about 1/3 of total P was found in the A&D layer (Tables 10 and 11). This suggests some leaching of P from litter material (Kartashov 1961, Manakov 1962).

Relationship of Total Nutrient Levels to Pine Growth

In Table 12 the nutrients have been reported as grams per pine stem, and Table 13 gives simple correlations between stand parameters and nutrients. Neither site index nor the cover of the ground flora are apparently linearly related to any nutritional expression of N, K, P, or Ca. However, the possibility that the subalpine stand, LHLP2, with Vaccinium myrtillus as a major ground species contains more forest floor N than the montane stands (cf. Tamm 1959) cannot be discounted. There is no strong correlation between pine density and total nutrients on the forest floor, and the somewhat higher correlations between density and nutrients as g/m^2 occurs because these variable are not a priori independent. For this reason, too, the nutrients expressed as g/m^2 have rather high correlations with stem volume. Nevertheless, the high correlations between stem volume and both P and K might suggest some limiting effect of these nutrients which are at low levels on the forest floor. In addition both P and N might have some effect on height growth of lodgepole pine.

The inclusion of stands 1-3, 4-3, and LHLP2 in correlation analysis has introduced sources of variation in pine stand parameters that are not attributable to nutrient factors. The partial thinning of stands 1-3 and 4-3 by man or fire explain much of their present density. The height of dominant trees in stand 1-3 is caused partly by their older age, while both height and volume growth in stand LHLP2 may reflect the influence of subalpine climatic site factors. These causes of variation could either obscure or enhance linear effects of total nutrients on pine growth, especially when only 8 stands are included in analysis. Wilde et al

Table 12. Nutritional resources as grams per stem in Colorado stands of *Pinus contorta*.

STAND	STEM VOLUME[a] (dm^3)	NUTRIENTS N	P	K	Ca
MLP2-2	3	9	0.6	5	11
2-1	13	17	2.1	7	21
4-1	27	41	4.4	19	24
4-2	28	47	4.2	19	38
1-1	35	38	3.8	33	43
1-3	170	163	16.0	67	210
4-3	95		15.0	79	150
LHLP2	210	135	12.5	66	78

[a] $V = 7.8D^2H$, where D is average Dbh (dm) and H is average height (m) of dominant trees.

Table 13. Simple correlations (100r) of variables in Colorado *Pinus contorta* stands.

STAND VARIABLES	NUTRIENT VARIABLES							
	N		P		K		Ca	
	Total	g/stem	Total	g/stem	Total	g/stem	Total	g/stem
Density	66	74	63	77*	34	78*	12	65
Stem Volume	84*	78*	60	87**	35	84**	34	72*
Height of Dominants	80*	53	80*	66	50	64	26	48
Site Index	31	25	45	16	36	13	27	41
Ground Cover	28	72	8	60	15	68	38	38
Total Litter	85*	36	75*	50	46	41	42	46

(1964) found that significant simple correlations between height growth in *Pinus resinosa* and available K or exchangeable Ca and Mg were meaningless when more critical variables such as soil texture, available P, and soil organic matter content were related to height growth in multiple correlation. Thus, significant correlations in Table 13 are suggestive but not conclusive.

In his discussion of possible factors restricting growth in pure pine stands Florence (1967) suggested that the buildup of rot resistant pine residues on the forest floor and the corresponding high C/N ratios, the possible adverse effects of litter extracts upon soil microorganisms, nutrient immobilization, poor mycorrhizal development where N or P may be in short supply, and adverse microbial antagonisms that might develop in pure crops over long periods could all limit stand growth. Climatic factors could also affect pine nutrition, especially on dry sites where comparatively few periods of litter wetting (which stimulates decomposition) occur during the year. Heinsdorf (1966) thought that low annual growth of pines on sandy soils during dry years could be due to reduced uptake of N and P by the trees. In some pine ecosystems the low supply of mineral nutrients resulting in poor growth has been remedied by fertilizer application (e.g. Hall and Raupach 1963), and the possible stimulus of fertilizer applications of N,P, or K on stem volume or height growth of lodgepole pine should be studied in field plots. For adequate growth of *Pinus resinosa* on coarse-textured Wisconsin soils Wilde *et al* (1964) considered minimum levels of available P and K to be 25 and 70 pounds per acre respectively. While requirements for lodgepole pine might be different, it is possible that total

levels of these nutrients on the forest floor are too low to provide an adequate supply on dry sites. The high correlations of Table 13 might be spurious, but they also hint that further study of nutrition and nutritional requirements of lodgepole pine should be made.

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APPENDIX - SOIL PROFILES

Profile 1. Bisequal Brown Podsolic-Gray Wooded Soil.

Location: 12 miles west of Boulder, Colorado at 8200 feet.

Relief: Upland site, 8% east-facing exposure.

Climate: About 20 inches mean annual precipitation.

Vegetation at profile site (MLP1-1): *Pinus contorta*, no herbaceous vegetation.

Date of Field Description: 7 August 1966.

HORIZON	DEPTH (in.)	DESCRIPTION
L1	1.5-1.3	Loose, continuous sprinkling of recently fallen pine debris: dark brown (7.5YR 4/4 dry) needles, dark red (2.5YR 3/6 dry) male cones, occasional female cones, bark flakes, and scattered twigs.
L2	1.3-0.5	Discolored (very dark gray, 10YR 3/1 dry), unfragmented needles and male cones, a few intact female cones, small twigs and bark flakes; spherical animal droppings ca. $\frac{1}{4}$ inch in diameter are scattered or in small concentrations. Boundary abrupt and wavy to smooth.
F1	0.5-0.2	Somewhat compact mat of mostly partly fragmented pine needles, but also including cones, cone scales, somewhat decomposed small twigs, spherical animal feces, and other debris. The state of fragmentation and compaction increases with depth so that the boundary is somewhat arbitrary. Horizon $\frac{1}{4}$-$\frac{3}{4}$ inches thick, boundary wavy and abrupt.
F2	0.2-0	Compact mat mostly of fine bits of pine needles under $\frac{1}{4}$ inch long. Reddish and sometimes charcoal scarred wood sometimes present. Horizon $\frac{1}{8}$-$\frac{1}{4}$ inch thick, boundary wavy to irregular, abrupt.
A2&D	0-0.1	Very dark brown or very dark grayish brown (10YR 2/2-3/2 moist) very fine bits of organic material infused with whitish fungal mycelia. Charcoal and fine reddish wood fragments common. Fine pine roots and their mycorrhizae common. Sprinklings of reflective, very fine sand grains are most evident at the lower boundary. pH 4.9. Horizon 0-$\frac{1}{2}$ inches thick, boundary wavy to broken, abrupt.

A2	-	Dark grayish brown (10YR 4/2 moist) loamy samd (or sandy loam) of sporadic and irregular occurrence and thickness, but rarely over $\frac{1}{8}$ inch thick. Boundary broken and abrupt.
B2ir	0.1-1	Dark brown (7.5YR 4/4 moist) gravelly sandy loam (or gravelly loamy sand) grading into brown (10YR 5/3 moist) gravelly loamy sand (or gravelly sandy loam). Massive and very friable. Charcoal fragments occasional. Fine pine roots common to abundant. Horizon 0-1$\frac{1}{2}$ inches thick, boundary irregular and abrupt.
B3	1-5	Brown (10YR 4.5/3 moist) with distinct, fine, common mottles of dark brown (7.5YR 4/4 moist) gravelly loamy sand (or gravelly sandy loam). Massive and very friable. Charcoal fragments uncommon. Pine roots common to abundant and somewhat larger in diameter. Horizon 2-5 inches thick, boundary wavy and clear.
A'2	5-9	Brown (10YR 5/3 moist) fine gravelly loamy sand. Massive and very friable. Pine roots common. pH 5.8. Boundary smooth or wavy, gradual.
B'1	9-18	Brown grading into dark brown (10YR 5/4 to 7.5 YR 4/4 moist) fine gravelly loamy sand. Massive and very friable. Bands of dark brown material are clay coated on the angular gravels and coarse sands at lower parts of the horizon. pH 5.7. Pine roots sparse. Boundary clear.
B'2ir	18-	(not described at this site)

Profile 2. Thick Gray Wooded Soil.

Location: 15 miles west of Boulder, Colorado at 8300 feet.

Relief: Upland site, 23% northeast-facing exposure.

Climate and Vegetation similar to Profile 1.

Date of Field Description: 3 August 1966.

HORIZON	DEPTH	DESCRIPTION
L	0.8-0.4	Recently fallen pine debris, unfragmented and little decomposed. Boundary abrupt.

F	0.4-0	Discolored, somewhat compact mat consisting mostly of fragmented pine needles and other fragmented pine material probably more than two winters old. Boundary wavy (sometimes broken) and abrupt.
A1	0-3	Black (10YR 2/1 wet) to brown (7.5YR 3/2 wet) fine gravelly loamy sand. Very slightly plastic and very slightly sticky. Loose or slightly coherent mineral particles. Charcoal fragments frequent, and pine roots common. Horizon 0-6 inches thick; boundary wavy to broken, clear.
A3	3-4	Brown (10YR 3/2 moist) fine gravelly loamy sand. Consistence as above; loose or very slightly coherent. Pine roots common. Horizon 0-3 inches thick; boundary broken and abrupt.
A2	4-14	Brown (7.5YR 5/3) when moist or pinkish gray (7.5 YR 6/2) when dry fine gravelly loamy sand. Very friable and soft; very weakly massive. Some charcoal. Pine roots common in upper 2 inches and much reduced in abundance below this level. pH 6.0. Horizon very wavy (sometimes broken), abrupt.
B1&A2	14-23	Dark brown (7.5YR 4/4 moist) fine gravelly sandy loam and horizontal bands of brown (7.5YR 5/3 moist) fine gravelly loamy sand. The dark brown material has weak, medium prismatic structure with thin clayfilms. The peds are easily fractured into fine angular gravels and loose sands. Pine roots sparce. Horizon up to 20 inches thick; boundary wavy and abrupt.
B2ir	23-74+	Yellowish red (5YR 4/6 wet) and strong brown (7.5YR 5/8 wet) fine gravelly sandy loam with pockets of gravelly sand and bands of dark reddish brown gravelly sandy clay loam. The pockets of gravelly sand contain large gravels that are easily broken by knife and readily crushed by hand into strongly angular fine gravels and sand. Structure not apparent. pH 6.1. Clay 19% of the less than 2mm material at 28-32 inches. Pine roots sparse.

4040

January 9, 1968

Dr. William H. Moir
Department of Forestry
The Australian National University
School of General Studies
Box 4, Post Office
Canberra, A.C.T., Australia

Dear Will:

I was very pleasantly surprised to receive your report on the cooperative-aid study that you were carrying out on nutrient cycling in lodgepole pine. My surprise was heightened by learning that the report was sent from Australia. I had forgotten that you were going to Australia, and I have a friend there named Bill Muir. My first reaction was why is Bill Muir signing "Will" after all these years!

I have not reviewed the report yet. I shall try to do so in the near future, and I am asking Bob Alexander and Cliff Myers to do likewise. We will get in touch with you after the reviews.

Best wishes to you and Mrs. Moir for your stay in Australia. We shall anticipate a renewal of our association upon your return to Colorado.

Sincerely yours,

G. L. Hayes

G. LLOYD HAYES
Assistant Director

cc: Bob Alexander
Cliff Myers

THE AUSTRALIAN NATIONAL UNIVERSITY

HEAD OF DEPARTMENT
PROFESSOR J. D. OVINGTON
PH.D., D.SC., F.F.S., F.I. BIOL.

DEPARTMENT OF FORESTRY
P.O. BOX 4
CANBERRA, A.C.T.
TELEPHONE 81 1244

January 5, 1968

Mr. G.L. Hayes
Rocky Mountain Forest & Range Experiment Station
Forestry Building
Colorado State University
Fort Collins, Colorado 80521

Dear Lloyd,

Enclosed are three copies of our report on forest floor nutrients in lodgepole pine stands. I feel that Herb Grier and I have met as many of the objectives of Line Project FS-RM-1201 as we had time and capability to do. We do not include Mg in the report because our flame photometric determinations for this nutrient did not produce reliable results. I hope, later, to make some Mg analyses on the forest floor material using Titan Yellow procedures. You will also find, Lloyd, that we were unable to do much in the way of meeting objective 3 (comparing total nutrients between lodgepole pine sites with and without evidence for replacement by Douglas fir). We simply had our hands full analysing the eight stands included in the report. I feel, however, that what we did accomplish has been thorough, reliable, and represents a big forward step in appraising nutrient factors in lodgepole pine forests in Colorado. Your effort in assisting this program at the University of Colorado has been greatly appreciated by both Herb and myself; and I sincerely hope that the enclosed paper comes up to your expectations.

We would appreciate your critical comments and those of Bob Alexander and Cliff Myer on the report, and would like to revise it as all of you see fit. Further, I would think it appropriate to prepare some or all of the material for publication - possibly in the Soil Science of America Proceedings in their section on Forest and Range Soils.

I look forward to returning to Colorado either in June or next August, and would like to resume discussions and conferences with you and your collegues on problems relating to forest productivity. The enclosed Research Prospective will give you a very brief rundown of some of the current and anticipated forest research at CU.

I am really enjoying Australia. You were so right about growth rates in Pinus radiata plantations - Wow! I have also seen for the first time subtropical rainforests, temperate southern beech forests, and the fastest growing hardwoods in the world - Eucalyptus regnans in Victoria and Tasmania. I'll give you full details when I return.

Yours sincerely, Will